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COUPLING SPECIES-LEVEL INVENTORIES WITH VEGETATION MAPPING

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ABSTRACT

The importance of high quality vegetation maps for land management is rapidly gaining recognition. Unfortunately, most vegetation maps in the western USA are old, have coarse resolution, or are not ground-truthed. Vouchers for these maps, even of the dominant species, are lacking. This makes natural resource management decisions, including those made during disasters such as fire, difficult or sometimes damaging because managers lack the basic information they need to make these decisions. In an effort to fill the information gaps, many vegetation mapping projects have been implemented across the nation, but those that want the maps often do not think of including species inventories in the mapping activities. At the same time, botanists continue to have difficulty finding funding for complete species inventories. This situation represents an opportunity to combine the skills of botanists with the needs of land managers. I present examples of vegetation projects I was involved in, in which I convinced the project leaders to incorporate plant species inventories in the mapping activities. The addition of species distribution information increased the quality, usefulness, and accuracy of these projects. Funding for species inventories can be found in restoration budgets. Botanists should take it upon themselves to involve themselves in mapping projects. Further, if botanists are willing to make their case, they should be able to convince the public and funding authorities to spend a little restoration money on species surveys before the need to restore arises.

It remains extremely difficult to obtain funding for floristic surveys in the United States. This is true in spite of a steady, high rate of new plant species discovery for the past 100 years in California alone (D. W. Taylor in Ertter 2000). Remarkably, most floristic work is performed *pro bono* by both professionals and amateur enthusiasts (Ertter 2000). However, this situation is far from ideal and seriously slows the work. As botanists interested in plant distribution patterns, we know that our knowledge is far from complete. To increase our knowledge of these distributions at the necessary pace, funding must support species inventories. Therefore, we must be creative about how we present proposals to do this work.

We need to learn how to convince management and funding agencies that species inventories are beneficial; not only inventories of vulnerable species, but also of the dominant, common, and uncommon species. We can seize opportunities to further this goal by finding vegetation projects in our area and presenting to project leaders reasons why making voucher collections will improve the project's usefulness. I here present examples from my experience of different situations where species inventories were included in, and improved the quality of, other projects.

VEGETATION MAPS

A vegetation map was probably the first graphic display of plant distributions. Vegetation maps originated with the military in order to provide basic information concerning the structure of vegetation pertinent to the movement of troops, maintenance of supply lines, cover, and other logistical concerns (Küchler 1967). In the western USA, the first wave of vegetation maps were made for the purpose of resource extraction, beginning with Merriam's life zones map (Merriam 1898). Through the 1950's, most of the nation's vegetation maps were economic, a trend that Jepson resisted for decades (2001).

Other important uses of vegetation maps began to emerge into the national arena in 1993 when the Gap Analysis Program (GAP) (Scott et al. 1993) was launched as a national project (Scott and Jennings 1997). However, plant species distributions are only rarely integrated into modern vegetation maps, in spite of rapidly developing Geographic Information System (GIS) technology. Even the GAP project concerns itself mainly with dominant plant species in order to predict the distribution of wildlife habitat (Scott et al. 1993), and species-specific distribution data are usually restricted to vulnerable species. Further, because of growing concerns about climate change, the abandonment of species-level surveys is considered prudent and these are being replaced by "plant functional type" classifications (Smith et al. 1997).

Today, most agency scientists know they need vegetation maps to serve as baseline data to manage public lands. These maps must provide both ecosystem level and species-specific information. One layer should include structural information, that is, the distribution of the kinds (e.g., needleleaf evergreen, broadleaf deciduous) of forests, woodlands, shrublands, grasslands, and riparian systems that occur on landscapes and in regions. Physiognomic and structural information is needed to manage for vital ecosystem functions (Küchler 1967; Smith et al. 1997) upon which we depend. This information is also essential when planning for wildlife, recreation, and emergency procedures during natural disasters such as fire and flood. In addition to managing for wildlife habitat and vulnerable species, accurate vegetation maps with species-specific data are needed to plan and conduct restoration projects, and to permit and monitor commercial activities. It is difficult to assign a dollar value to species-level surveys because they produce irreplaceable basic information. However, many existing vegetation maps are fraught with problems, even at the structural, functional level.

Technical aspects. Many of the most utilized maps are old (e.g., Wieslander 1940) or have coarse spatial resolution (e.g., Küchler 1964). Most modern maps lack ground-truthing, have little species distribution data, and only a few recent maps have vouchers. Our vegetation maps need this species-specific distribution data and ground-truthing. We can easily correct all these deficiencies at one time with some planning and a modest budget.

Tying the species information to the vegetation map is easiest when the vegetation classes on the map are delimited by polygons in a GIS. I use the term polygon here to mean an irregular shape on a map with a sharp boundary that corresponds to an area on the ground of relatively homogeneous vegetation (whose boundary on the ground is rarely so sharp). Polygon-based mapping allows for a species-level inventory and the collection of vouchers during the ground-truthing phase of map production because collections and observations can be made within and recorded for individual polygons. The polygons can be identified from aerial photography, as I did (Charlet 2000) by using the methods of Küchler (1967), or from satellite imagery as Hogg et al. (1999) did by using the image segmentation approach of Ma et al. (2001). Once the polygons are in digital form, it is a simple matter to include species data in the attribute table when the voucher location data are precisely recorded. In this way, each polygon gets a species list. The hardest part of these surveys and mapping activities on the ground is actually getting to the sites. Once there, it is a simple matter of making voucher collections and adhering to strict record keeping standards, such as those recommended by Ferren et al. (1995). Species-specific distributions are easy to add to a polygon-based GIS map, even after the map is complete, by simply adding these distributions to the attribute table.

SPECIES INVENTORIES CONCURRENT WITH OTHER PROJECTS

Nevada wildlife map. In 1993, a research group at the University of Nevada was mapping wildlife habitat in Nevada. Since I spent much time in Nevada's outback while conducting my Master's and Ph.D. research, this group approached me to fill in the details concerning the distribution of trees throughout the state and to make a vegetation map of the state. I set about to construct a 1:1,000,000 scale map of the eight vegetation zones of Billings (1951) for Nevada.

In mapping the vegetation of Nevada, I included the distribution of the different conifer species and mapped their occurrences. It was easy to collect vouchers after going to the trouble of getting to and climbing these mountains, and so I did. Once the time allotted for field work was complete and I looked at my list of collections, it appeared that I had more than 100 cases of species in mountain ranges not accounted for in the literature (e.g., Little 1971).

I was troubled by this result, and wondered how many of my "range extensions" were in herbaria but had not been compiled. I went to 15 western herbaria with large Nevada collections, and found even more conifer distributions that were neither mapped by Little (1971) or Griffin and Critchfield (1972), nor used in previous analyses (e.g., Wells 1983). The changes were significant enough to warrant a new analysis, the results of which demanded strikingly different conclusions (Charlet 1995). Careful scrutiny of my collections led to other discoveries, such as extensive gene flow between several juniper taxa in the region (Terry et al. 2000).

Further, since publication of my conifer data for Nevada (Charlet 1996), others and I have found 6 new county records for 4 species, and 12 new range extensions. Altogether, information regarding the distribution of 8 of these 22 species and 9 different mountain range conifer floras have changed since 1996. There are more than 4000 vascular plant species in the Great Basin/Mojave Desert region, but Nevada's conifers represent less than 0.6% of that flora. Clearly, we have only begun to map the distribution of the flora in detail. In fact, we are still mapping the dominant species in the region.

Lake Tahoe vegetation and wildlife maps. The New Year's Flood of 1997 was a harbinger of a year filled with startling events in the eastern Sierra Nevada (Horton 1997). The world-famous transparent waters of Lake Tahoe had lost 8 m of clarity in the previous 32 years (C. Goldman *in* Elliot-Fisk et al. 1997), leading to a serious examination of the causes. In its final report to Congress, the Sierra Nevada Ecosystem Project cited loss of water clarity, drought, disease, and threat of catastrophic fire (Elliot-Fisk et al. 1997). President Clinton then convened a Presidential Summit at Lake Tahoe in July 1997, a result being the declaration of Lake Tahoe a national treasure. The President initiated a large cooperative effort between the federal government, California, and Nevada that would preserve the lake (Clinton 1997). The federal portion of the $900 million funding for 10 years of monitoring and restoration projects received final congressional approval in November 2000 (Las Vegas Review-Journal 2000a).

To understand the ecosystems of Lake Tahoe, it is necessary to have a reliable vegetation map. Fortunately, by the time of the Lake Tahoe Presidential Summit, the GAP projects in both California (Davis et al. 1998) and Nevada (Edwards et al. 1996) were complete or nearly so. It seemed simple to splice the maps, which the GIS technicians at a laboratory at the University of Nevada did. The resultant hybrid map of the Carson Range had serious problems that led the Director to call me to see if I could devise a quick fix.

I began by collapsing the two different classification schemes used on the maps to a simpler set of fewer classes (14) that were held in common by both maps. However, in the best reclassification scheme that I could devise, only 40% of vegetation classes along the edges matched. Even at the structural level of forest, shrubland, and meadow, only 62% of the vegetation across the state boundary agreed. The only solution was to start over, and so I began developing new vegetation and wildlife maps for the Carson Range. I had one assistant and two months in the field to map 55 cover classes across 1340 square kilometers at 1:48,000 scale. Given so little time and so much ground to cover, the distributions I was concerned with were mainly the woody species. Nevertheless, this work yielded 7 new county records for 5 conifer species; this in a world-famous area within 100 miles of 2 major universities.

The maps I produced for the Carson Range covered only about half of entire Lake Tahoe basin, but their total cost was a mere $36,000, or 0.04% of the $900 million earmarked for Lake Tahoe restoration. Further, this database is versatile, serving multiple functions simultaneously due to how the data were structured. The complete set of cover classes can be converted easily to structural classes or to wildlife classes according to the wildlife habitat types of California (Mayer and Laudenslayer 1988). In the attribute table, each forest polygon has a species list, in descending order, of the arboreal species. Species with an attendant collection in the polygon are noted. Further, the design of the map and accompanying attribute table lend themselves to further augmentation with species-specific information in the future.

Nevada Science Teacher Enhancement Project (N-STEP). What better way to promote high school science education than to introduce teachers and their best students to the construction of a scientific vegetation map in a remote Nevada wilderness? I thought this was my idea, but I learned later that Jepson (1934, 1935, and 2001, this volume) was doing something similar at U.C. Berkeley 80 years ago. It was Jepson's student who made the vegetation map I admired the most (Wieslander 1940), and this project collected more than 20,000 vouchers now at U.C. and elsewhere (Ertter 2001).

My teams' efforts in 2000 resulted in the discovery of a new Nevada record, *Disporum trachycarpum (David Charlet 2649 and Orne Grant UNLV, RENO).* A key to this find was that our group had a visible presence in and demonstrated respect for the local community. In fact, this find was in Jarbidge Canyon, merely 5 weeks after and 5 miles from the Jarbidge Shovel Brigade protest (San Jose Mercury-News 1999, Times-News 2000). The ironic twist is that we were led to the plant by a protester and resident who had lived there for decades.

GAP and re-GAP projects. GAP maps exist for all the states, and some states are beginning re-GAP projects (Scott and Jennings 1997). Regardless of the status of the GAP map of your state, GAP projects are opportunities to conduct species inventories while mapping vegetation. We should grab this opportunity and either improve the map during the re-GAP project, or ground-truth the existing GAP map. At the same time, we can conduct species inventories and collect vouchers, thereby improving the map, our herbaria, and our floristic database.

Where Is the Money?

Big money is spent on our wildlands in two relevant areas: fire and restoration following fire. For example, Nevada's first fire in the 2000 season, the Buck Springs Fire, conveniently occurred in the Spring Mountains in sight of my house as I was preparing this manuscript. I was shocked to learn that it cost $1 million to fight this 2000 acre fire (Las Vegas Review-Journal 2000b). One helicopter alone costs $53,000/day + $4000/hr. I admit it occurred to me that the daily fee is greater than my annual salary as a community college professor.

But that was just one little fire in an ongoing firestorm. In early July 1999, a Nevada official declared the fire season was "of Biblical proportions" (Reno Gazette-Journal 1999a) and the season ultimately consumed 1.8 million acres in Nevada (Los Angeles Times 1999). Fire-fighting costs for the 1999 fire season in Nevada included $6 million incurred by the state and $225 million by federal agencies (Reno Gazette-Journal 1999b). The crisis led Nevada Governor Guinn to announce what is probably the largest restoration project in the history of the world (Reno Gazette-Journal 1999c), with $15 million in restoration costs anticipated. So for the 1999 cost of fires in Nevada alone, there is a price tag of $246 million. Another 660,000 Nevada acres burned in 2000 (Western Great Basin Interagency Fire Center 2000) and restoration plans are proceeding (Las Vegas Sun 2000). Nationwide, the Secretaries of Interior and Agriculture recommended to the President in September 2000 that $2.8 billion be spent for wildland fire programs, including $150 million for post-fire stabilization and restoration (USDA Forest Service 2001).

Nevertheless, I must ask myself, what species will be seeded and what seed will be used? These questions lead me to an answer to another question: How can species-level inventories fit into this spending? The answer is the seeds. Due to high demand and low availability, sagebrush seed now sells for up to $100 per pound, up from $30 per pound in normal years (Las Vegas Sun 2000). Here is a way to help floristic surveys to pay for themselves during the short term: include seed collecting activities with voucher collecting and ground-truthing.

In addition to our ignorance of the flora and its precise distribution, there is much disagreement about what "restoration" is (Billings Gazette 2000; Elko Free Press 2000). This situation has led the western USA to what I have called elsewhere a "biogeographic crisis" (Charlet 1999). This crisis, as relevant here, involves species distribution, relative population levels, and the use of non-local or non-native seed in restoration projects.

Even in areas where we have a good idea of the flora's distribution, when large fire and flood emergencies occur, there can be no consideration for replanting the region with seed from local populations. We use what seed can be bought, no matter what the source. The introduction of other gene pools into a breeding population is background noise to the biogeographic signal present in the population's genetic diversity, and may compromise the population's long-term stability in the area. Further, these introductions threaten our ability to use our powerful new molecular biology techniques that allow us to look at a population's DNA and to examine the nuts and bolts of its evolution. Great Basin ecosystems are reacting to recent changes in fire frequency and timing (Tausch and Nowak 2000) as well as water diversions and development (Castelli et al. 2000). Biogeographic patterns are clouding, and these changes may be irreversible. It is essential that we use the correct seed in the correct places, and we cannot do this without baseline data and an established seed bank, both organized at the population level.

CONCLUSIONS

We can combine vegetation mapping with inventories by embedding polygons with species data into a GIS, and these species distributions should be documented, whenever practical, with vouchers. We also should collect seeds from the areas where we do our inventories and vegetation mapping. To be successful, the efforts of academia, agencies, and the public need to be coordinated and complementary.

Our knowledge deficiencies include ground-truthing and species inventory. To correct this, we must convince the public, legislators, and agencies that knowledge of this kind is inherently valuable. We need to take it upon ourselves to persuade everyone that this basic knowledge is valuable, and spending money to obtain basic knowledge is a good investment. Clearly, our restoration can only be as good as the information available. There is money: a mere 1% of $15 million restoration costs for the 1999 Nevada fire season could yield $150,000 for species inventories and vegetation maps. Nationwide, only 1% of the $150 million earmarked for restoration following the 2000 fire season could represent $1.5 million for a large national survey.

The health and management of our ecosystems has captured the attention of both the public and its elected representatives, especially since the 2000 fire season consumed 7.3 million acres in the USA (National Interagency Coordination Center 2000). These fires cost hundreds of millions of dollars to fight and hundreds of millions more in lost revenue. This public interest led the Western Governor's Association to have wildfires as the topic of their Winter 2000 meeting (Billings Gazette 2000). Throughout these meetings and plans, agencies must act as if ecosystem processes are understood and the distribution of all species is known, and the public expects that the right decisions are made. But these things are not known. We are only now learning where the dominant species are, much less all the species in the flora. It is in the public's interest that we obtain the basic information on the distribution of the flora, but it is up to us to convince the public that this is so. Vegetation maps, species data, and local, native seeds: all are needed for good resource management. With a little more effort than required for the vegetation map alone, we can include species inventories and seed collections and so enhance these projects.

Stimulating collaborations and powerful consensus can only arise when all parties are involved. We botanists, regardless of our affiliation or "amateur" status, need to cultivate relationships with every group. If we do, we will probably be surprised at what a tremendous pool of expertise and knowledge to which we have access. Local citizens are botanist's allies. They live on the land, have intimate knowledge of their landscapes, and can take us to their special places. Agency land managers and scientists are also botanist's allies: they got involved because they love the land and they love to serve the public. Outdoor recreationists are our allies too, as indicated by their choice to play outside on the land rather than in the gym. I would be remiss if I did not mention that more than once recreationists saved my crippled vehicle and me. Academicians are allies, especially if you come bearing good data and fine collections. Surely all parties will find common ground in the need to know what is on the ground and why, before we spend public money to restore it.

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